TESTS ON A MARTIN ROTARY CONVERTER

BY

M. F. BACON

R. H. RENSCH

ARMOUR INSTITUTE OF TECHNOLOGY

1919

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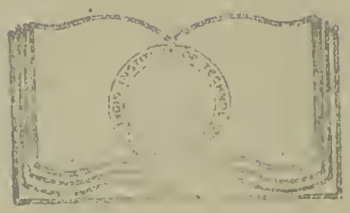

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converter

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TESTS ON A MARTIN ROTARY CONVERTER

A THESIS

PRESENTED BY

M. F. BACON AND R. H. RENSCH

TO THE

PRESIDENT AND FACULTY

OF

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE

IN

ELECTRICAL ENGINEERING

MAY 29, 1919

APPROVED

Professor of Electrical Engineering

Dean of Engineering Studies

Dean of Cultural Studies

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Electrician, Nov. 23, 1917

Feeder Tap Resistance in Rotary
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Elec. Ry. J. 45:799-800
April 24, 1915.

Motor-generators versus Rotary
Converters.
Power. 42:458
Sept. 28, 1915

Practical Notes on Rotaries.
Elec. R. & W. Elec'n. 66:989
May 29, 1915

Pressure Regulation of Rotary Converters.
Electrician, Nov. 9, 1917

Protecting Synchronous Converters

Power 42:171-2

August 3, 1915.

Synchronous Motors and Converters

Blondel.

Design Data.

10 Kw. Two Phase, 220 volts a.c.

110 volts d.c.

Armature: 1.1.1

1 turn per bar 4 #14 D.C.C.

Connection: 1:68 (wave)

Length of loop, 15 inches.

D.C. speed 1850 r.p.m.

Shunt fields:

950 turns #19 S.C.C.

Damper ring winding:

42 turns per coil 1#8 sq. D.C.C.

Brushes:

D.C. 8 - 2x1 1/4x1/2 H.G. 16

A.C. 1 7/8 x 1 x 5/8 E.H. 8

Transformer:

Primary 220, Secondary 72 - 92

Core 2 x 8 x 9 1/2

Primary turns 130-2 #9 sq. D.C.C.

Secondary turns 59 - 2 #5 sq. D.C.C.

Brimary taps 1-125-130 front.

Taps No. 1 on rear.

Secondary taps, 44-45-46-47-49-

51-53-55-57-59.

Relay Coil 1000 ohms.

Trip coil wound with #28 S.C.C.

Shunt coil wound with 22000 turns

#33 S.S.E.

Reverse Current Coil 9 turns 6 #9 sq.

Dimensions of damper ring 6 x 8 inches.

OBJECT.

A very considerable portion of the apparatus used in the distribution of power by the large central station companies consists of rotary converters. Considerable quantities of power are transmitted over very long distances on high tension alternating current transmission lines, and at the substations the alternating current is transformed or rectified to direct current by means of the rotary converters for any purpose for which direct current may be not only desirable but necessary.

The small rotary converter also holds a very important place in city districts where there is an alternating current supply but where direct current is desirable for the operation of motion picture arcs and necessary for charging storage batteries.

It is upon one of these machines, designed for primarily for storage battery charging, motion picture projection and arc welding that the tests described in this thesis were made.

In the present day development of large central station power installations, it may conservatively be estimated that ninety per cent of the total output of power companies for commercial distribution is alternating current. In such branches of service as electric railways, cranes, elevators and in general all types of variable speed machinery where alternating current is far from satisfactory if not altogether impracticable, it is common practice to convert or rectify the alternating current supply to direct current.

Running almost parallel to the rapid growth in the output capacity of power equipment varying from 5000 kw. per unit in 1903 to 45,000 kw. per unit in 1918, we find two other industries more or less closely related to it, which have grown to amazing proportions in the same period of time.

It was an acknowledged fact fifteen years ago that the automobile had established itself as a commercial necessity, yet the developments of the past decade, especially in electrically driven cars and trucks, has passed the wildest predictions of that time. In much the same manner although in a shorter and more recent period of time the motion picture has passed from the state of an experimental novelty to the point where in many localities it has completely supplanted every other form of entertainment. The connecting link between the large central station and the two industries just mentioned may not be evident at first sight. A little consideration, however, will clear this up very nicely. The development of larger stations was dependent more or less upon the means of transmitting large amounts of energy without serious losses. This problem has been very successfully handled in general

by the high tension transmission systems running out for distances up to 150 miles in common practice. Then at various settled centers as small rural settlements, etc, a small stepdown transformer station is installed, the station having sufficient capacity to supply the community. Thus with electricity at almost any point among the road and in every small town, it is not difficult to understand how moving picture theaters were scattered broadcast throughout the country, and one seldom has to travel many miles along a main road to find a garage equipped with battery charging facilities.

In all battery charging work it is necessary to have a supply of direct current, while in the motion picture projector using the arc for illumination direct current is very desirable if not altogether essential. Consequently many methods have been utilized

to convert or rectify the alternating current supply to the direct current required. While improvements in the various types of gas filled incandescent lamps have made substitution suitable in some cases, yet the vast majority of projectors use arc illuminants.

Among the various methods of rectifying the alternating current we find the mercury arc rectifier, used on single and three phase; the electrolytic rectifier or relatively low efficiency and suitable for such loads as X-ray machines and small testing outfits; and third the mechanical rectifier, also of very low efficiency and limited service. On the other hand small motor-generator sets have been used with success, necessitating two machines, however, with additional attention.

The rotary converter built in relatively small sizes has been tried with varying degrees of success. It is on a special design of this

type of machine known as the Martin Rotary Converter, built by the Northwester Electric Company of Chicago, that this test was made.

The Martin Rotary Converter was designed with the idea of obtaining a nearly constant direct voltage throughout the entire range in load. In this respect it is very similar to the split pole converter, but the results are obtained in a very different manner.

The chief difference between this machine and the split pole converter is in the design of the field structure. This consists of a four pole shunt field, wound the same as for a four pole shunt motor. The pole pieces are cast integral with the frame; and the pole tips are machined in order to provide a force fit for the damper ring. The damper ring, built of laminated steel, forms a continuous magnetic circuit

from pole to pole, and has alternate slots and squirrel cage bars on the inner periphery. These slots and windings are shown in the drawing of the field structure. The series winding appears between the shunt poles, and is wound around the damper ring. Wound in the slots of the damper ring, and around the series winding, the planes of the two coils being perpendicular, is a winding which is short-circuited upon itself. Among the design features suggested at various times was one in which this winding, instead of being short-circuited upon itself, was connected in series with the compound winding in order to provide an interpole and thereby produce better commutation. But it was found that this did not improve the commutation; and therefore the next change was to short-circuit this winding upon itself. This is the situation in the machine in question.

From a study of the field structure it is evident that this winding acts in exactly the same manner as the squirrel cage winding. For that reason they will both be considered together as a squirrel cage winding.

At first sight it appears that the shunt flux under no-load conditions would be short-circuited from one pole to the next and therefore would not pass through the armature winding. This is prevented by notching the damper ring so as to reduce the cross-section and thus increase the reluctance. A small part of the shunt field flux is sufficient to saturate this section; the remaining flux is then shunted through the air gap and the armature circuit.

The armature reaction tends to weaken the trailing pole tip with respect to

the voltage, and thereby reduce the flux. This effect will cause the direct e.m.f. to decrease more or less rapidly. The effect of this when a Martin Rotary Converter is used for supplying power to motion picture arcs, would be to cause a fluctuation and unbalanced condition when more than one arc is used. The series field tends to overcome the armature reaction at the trailing pole tip and therefore stabilizes conditions when the load is variable as is always the case in moving picture operation.

Even when a steady load is being carried by the machine the series field flux first overcomes that part of the shunt field flux which is shunted through the narrow section of the damper ring. After this part of the shunt field flux has been neutralized the series field flux continues to increase and overcome the armature reaction at the

trailing pole tip. This action in this machine is just sufficient to overcome this part of the armature reaction, but it may be made sufficient to over-excite the field, so that there will be a rise in voltage and a strongly leading current at high loads.

The squirrel cage bars are placed in the small circular holes shown in the damper ring. As has been stated the short-circuited windings act in the same manner as the squirrel cage, so that they will here be considered as a part of the squirrel cage. Because of the squirrel cage winding, the Martin Rotary Converter starts as an induction motor. When the armature comes to very nearly synchronous speed it is pulled into step by the shunt field. The squirrel cage winding also prevents hunting, and also shunts the armature flux from the shunt field at start so that there is no high e.m.f. set up in the shunt field

as is the case in many machines. In this manner all danger of a breakdown of the insulation of the shunt field is avoided and no field break up switch is required.

In connection with the study of the field structure it will be well to study the flux distribution curves in order to understand how the the desired results are obtained with this peculiar type of field structure.

From a study of the flux distribution curves it is probable that a third and a fifth harmonic are present in the voltage wave. These, however, are apparently of minor importance in this particular machine. The "hump" in the full load flux wave is probably due to the increase of the flux from the series field and the hollow is due to armature reaction. The cross-magnetization of the armature shifts the

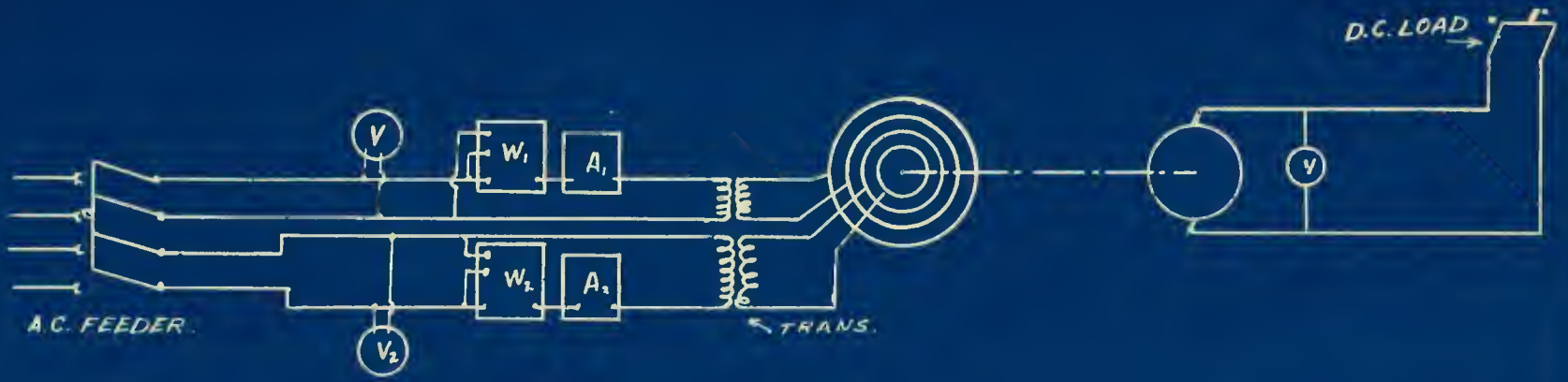
full-load flux in the direction of rotation.

The area under the curve of full-load flux distribution is less than that under the curve of no-load flux. This does not seem to be consistent with the fact that the voltage drop is so small even at high overloads. In making the test for the flux distribution the voltage across the primary of the transformer was kept constant. At no-load the power factor is approximately fifty per cent lagging and the current is seven amperes. The power factor at full load is practically unity, the RI drop of the armature will then be in phase with the voltage and the reactance drop will be in quadrature with the voltage. The resultant voltage across the collector rings will then be greater for the full-load condition than for the no-load condition. For this reason the direct voltage will be

kept at a nearly constant value even if the total flux is less under the one condition than under the other.

In the operation of a machine of this type there are several characteristics in which an intelligent purchaser is bound to be interested. Such features as over-all efficiency, voltage regulation, heating effects and power factor will be given special consideration. In an effort to produce the most satisfactory results in these effects, the manufacturer and designer have obviously been compelled to determine other fundamental characteristics such as flux distribution, etc, which are described elsewhere.

To be sure that the tests would be true to commercial service conditions, two types of load were used: namely the lighting load and the storage battery load.



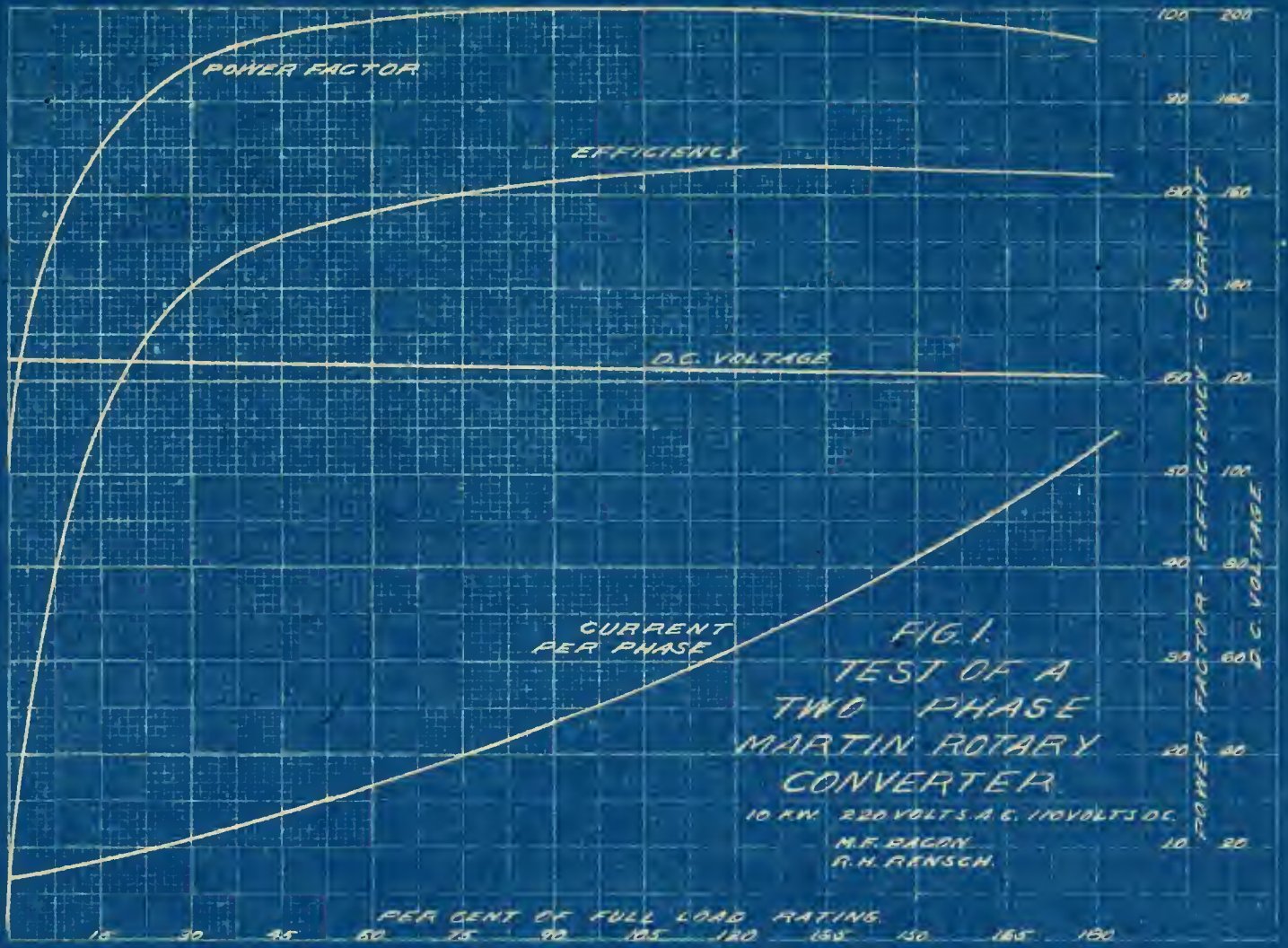
DIAGRAM

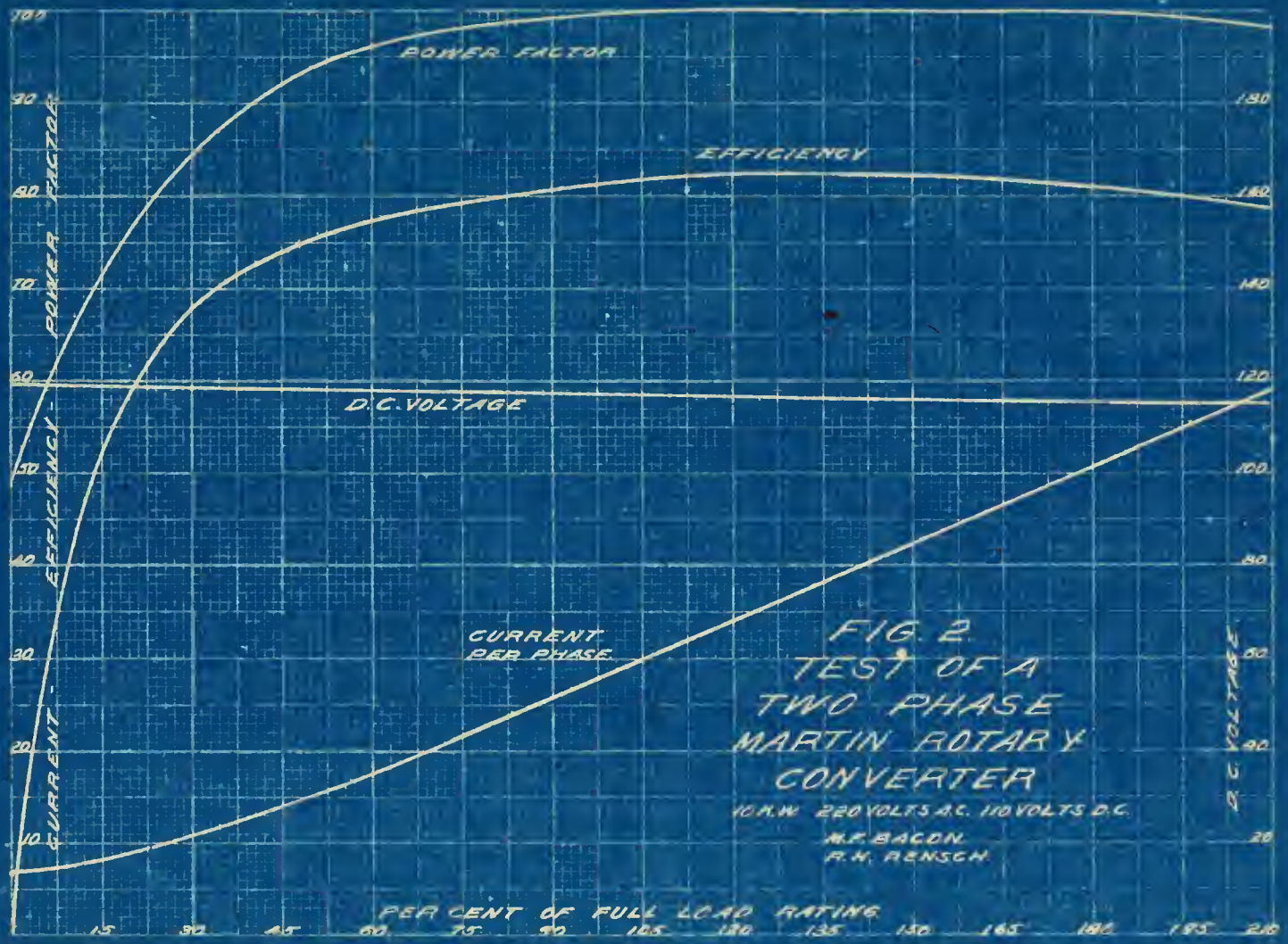
In the battery charging duty it is frequently desirable to charge at a lower rate or with a lesser number of cells and consequently a lower direct voltage is desirable. This is readily accomplished in this unit by shifting the transformer secondary contact lever to the desirable percentage tap. Ten taps are brought out from the transformer secondary giving a range in voltage from 34 per cent to 45 per cent of the applied alternating e.m.f.

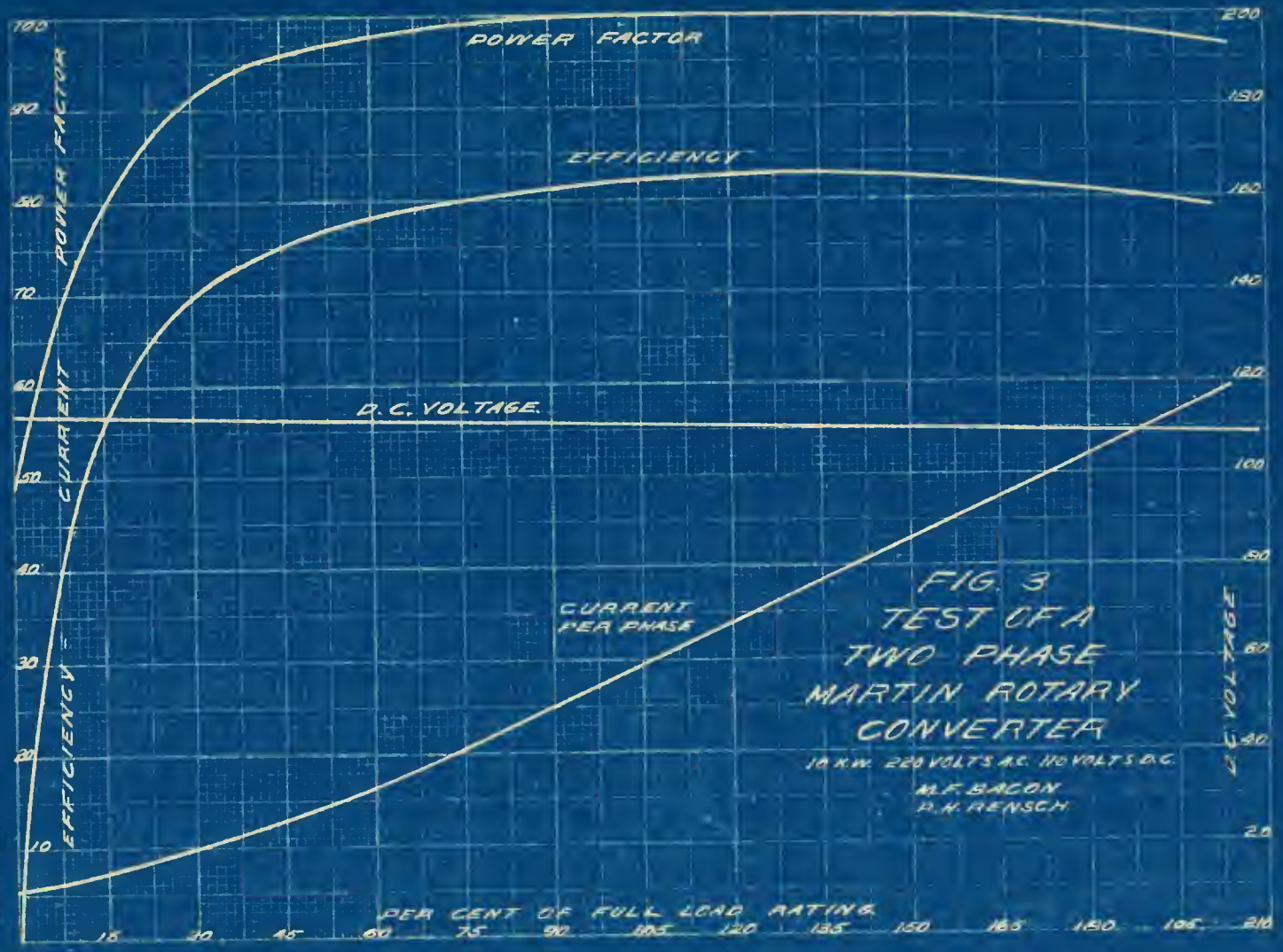
The first test under actual operating conditions was made with the maximum voltage ratio and consequently the maximum direct voltage with an incandescent lamp load. The shunt field was adjusted with a rheostat to a value which gave practically unity power factor at full-load, and left that way throughout the run. With the voltage kept constant at 220 volts and the frequency

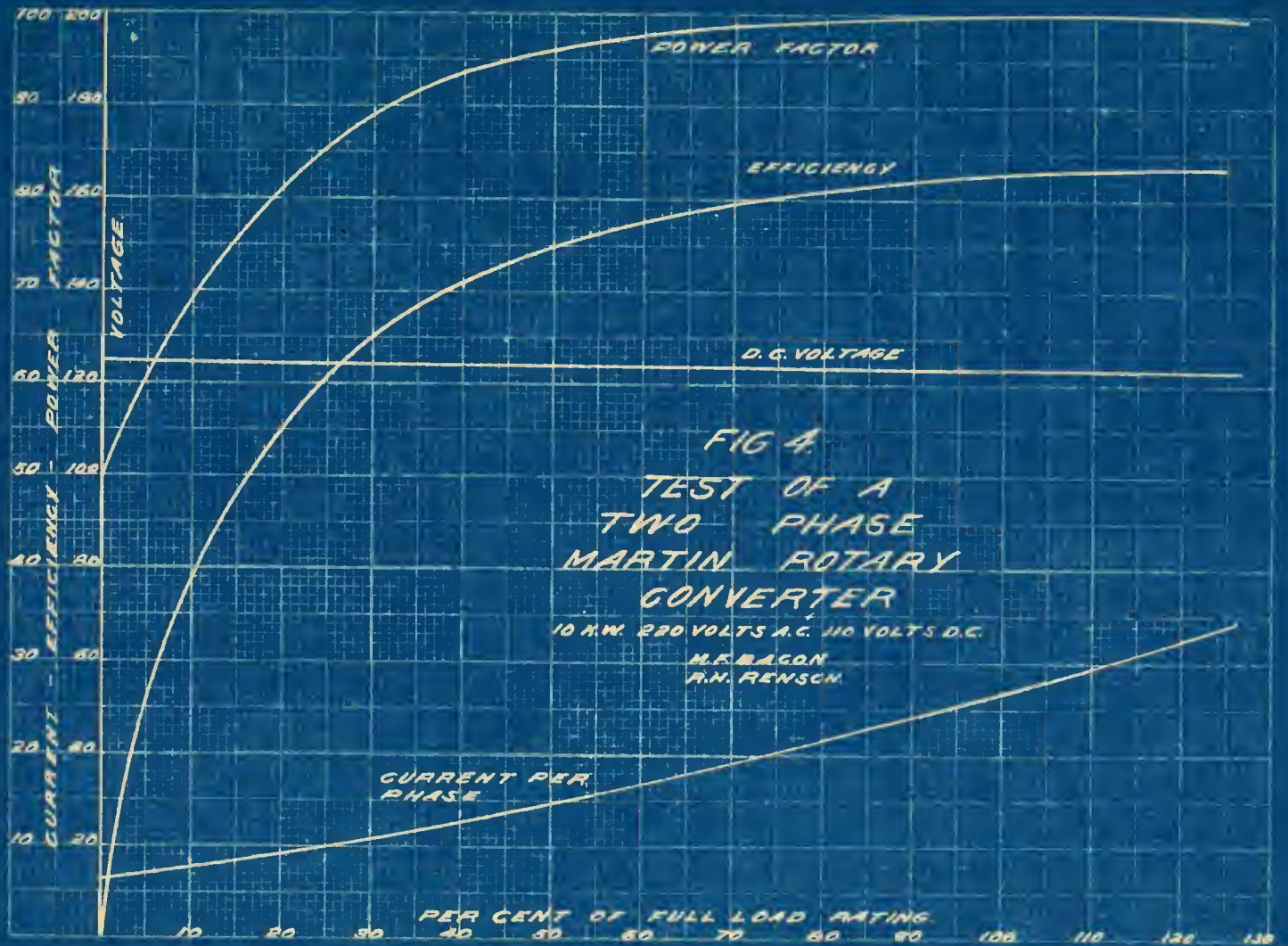
approximately constant at sixty cycles, the load was gradually increased to over 180 per cent of the full-load rating. At this point h they voltage regulation, power factor and efficiency held up well to those of normal load conditions, as indicated in the respective curve of Figure 1. Commutation was quite satisfactory with this load. The value of the auxilliary field winding can be better appreciated at this point in view of the fact that the 200 per cent load was suddenly thrown on and off several times with no apparent effect on commutation, no tendency to hunt and a fairly constant regulation.

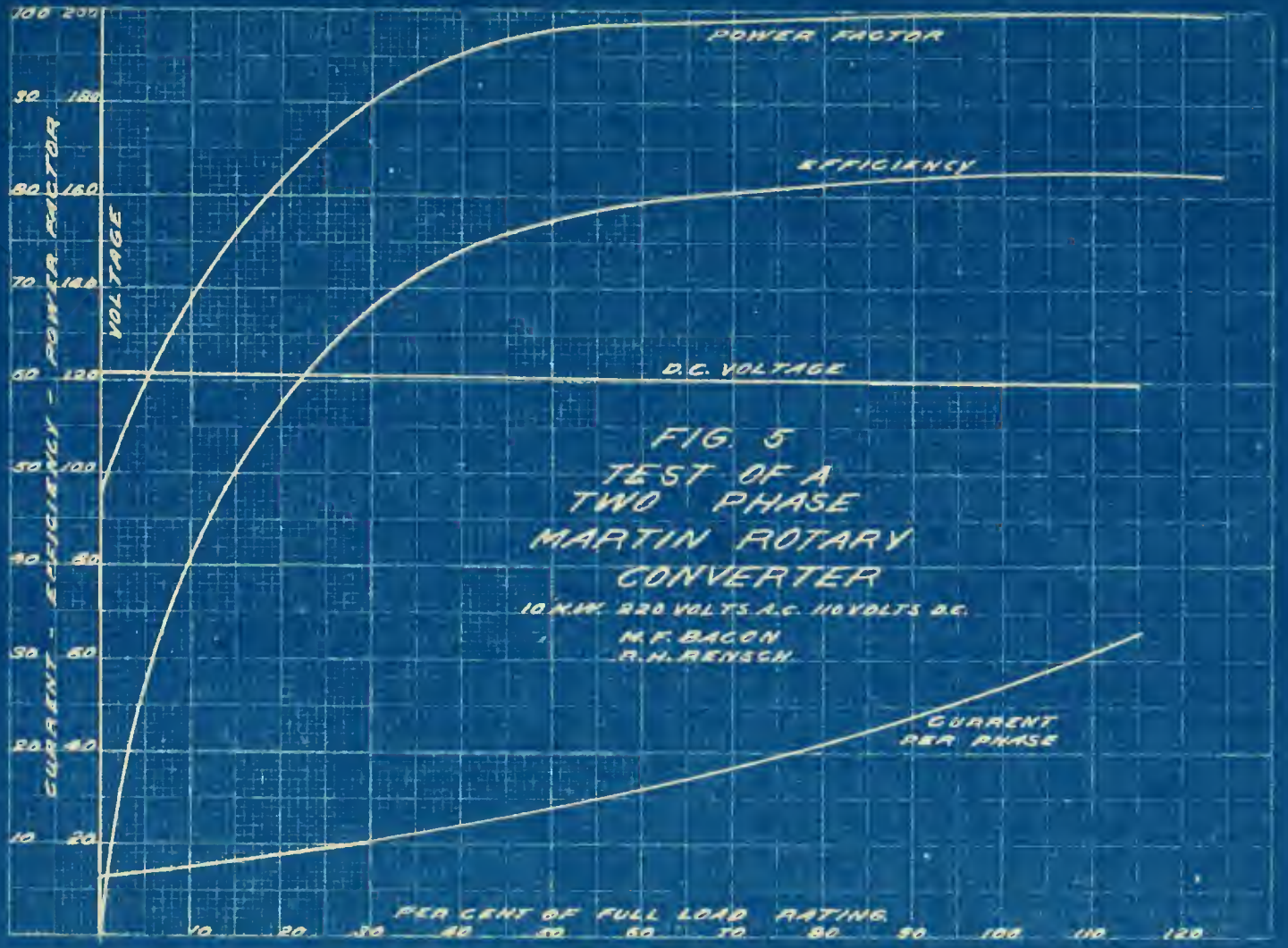
A study of the operating curves of Figure 1 indicate approximately 50 per cent power factor at no-load with a full field. The power factor rises rapidly to 95 per cent at 30 per cent load and practically unity power factor from 75 to 135 per cent load.


POWER FACTOR
EFFICIENCY
D.C. VOLTAGE
CURRENT PER PHASE
PER CENT OF FULL LOAD RATING.
15 30 45 60 75 90 105 120 135 150 165 180
POWER FACTOR - EFFICIENCY - CURRENT
D.C. VOLTAGE
100 200
90 180
80 160
70 140
60 120
50 100
40 80
30 60
20 40
10 20
FIG. 1.
TEST OF A
TWO PHASE
MARTIN ROTARY
CONVERTER.
10 K.W. 220 VOLTS A.C. 110 VOLTS D.C.
M.F. BACON
R.H. RENSCH.


POWER FACTOR
EFFICIENCY
D.C. VOLTAGE
CURRENT PER PHASE
POWER FACTOR
EFFICIENCY
CURRENT
D.C. VOLTAGE
PER CENT OF FULL LOAD RATING
FIG. 2
TEST OF A
TWO PHASE
MARTIN ROTARY
CONVERTER
10 K.W. 220 VOLTS A.C. 110 VOLTS D.C.
M.F. BACON
R.H. RENSCH


POWER FACTOR
EFFICIENCY
D. C. VOLTAGE.
CURRENT PER PHASE
POWER FACTOR
EFFICIENCY
CURRENT
VOLTAGE
PER CENT OF FULL LOAD RATING.
15
30
45
60
75
90
105
120
135
150
165
180
195
210
100
90
80
70
60
50
40
30
20
10
200
190
180
160
140
120
100
80
60
40
20
FIG. 3
TEST OF A
TWO PHASE
MARTIN ROTARY
CONVERTER
10 K.W. 220 VOLTS A.C. 110 VOLTS D.C.
M.F. BACON
P.M. RENSCH


POWER FACTOR
EFFICIENCY
D.C. VOLTAGE
CURRENT PER PHASE
VOLTAGE
POWER FACTOR - EFFICIENCY - CURRENT
PER CENT OF FULL LOAD RATING
100 200
90 180
80 160
70 140
60 120
50 100
40 80
30 60
20 40
10 20
10 20 30 40 50 60 70 80 90 100 110 120 130
FIG 4.
TEST OF A TWO PHASE MARTIN ROTARY CONVERTER
10 K.W. 220 VOLTS A.C. 110 VOLTS D.C.
M.E. BAGON
A.N. RENSCH


POWER FACTOR
EFFICIENCY
D.C. VOLTAGE
CURRENT PER PHASE
CURRENT - EFFICIENCY - POWER FACTOR
VOLTAGE
PER CENT OF FULL LOAD RATING
100 200
90 180
80 160
70 140
60 120
50 100
40 80
30 60
20 40
10 20
10 20 30 40 50 60 70 80 90 100 110 120
FIG. 5
TEST OF A
TWO PHASE
MARTIN ROTARY
CONVERTER
10 K.W. 220 VOLTS A.C. 110 VOLTS D.C.
M.F. BACON
R.H. RENSCH

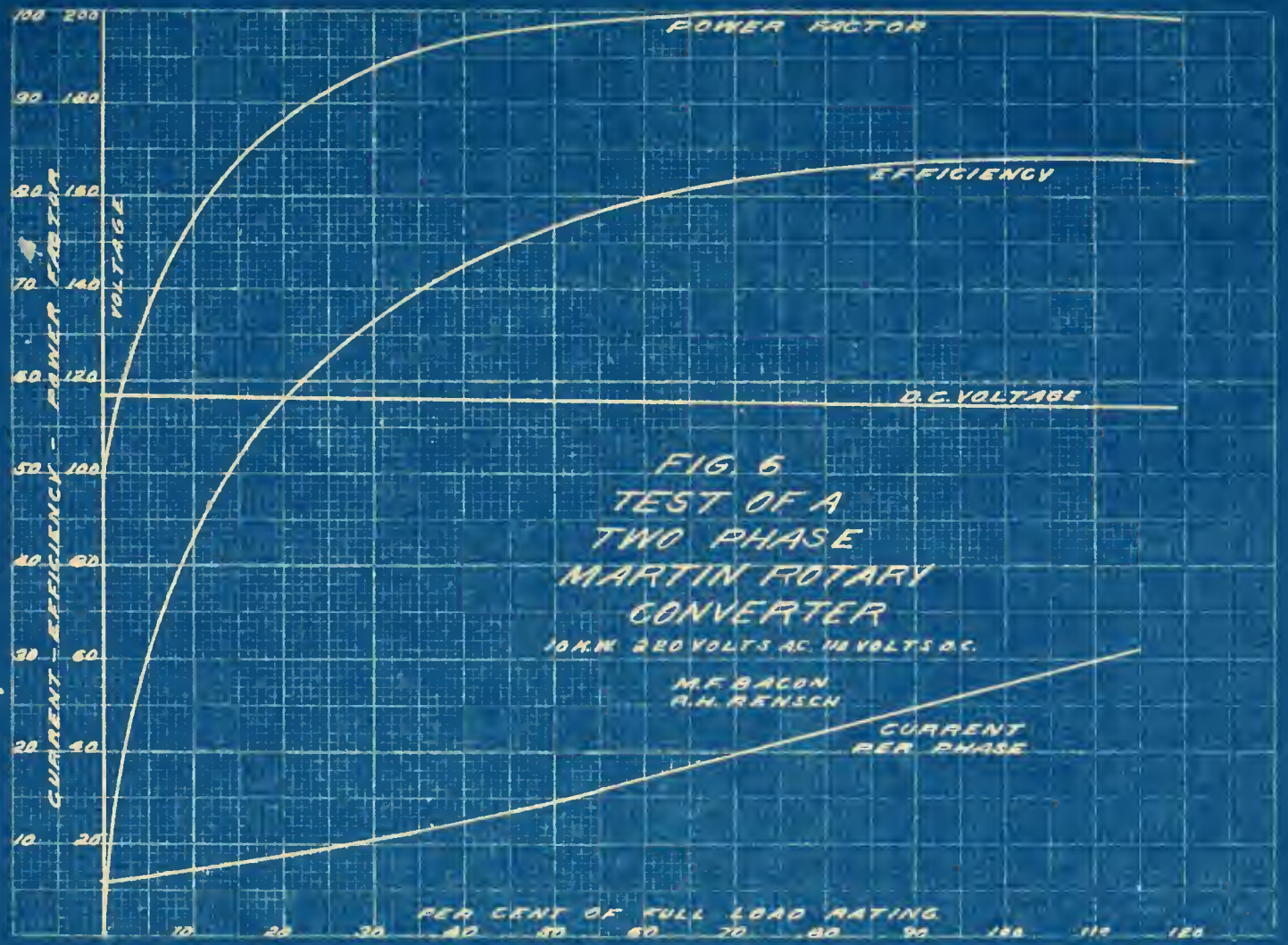


FIG 6
TEST OF A
TWO PHASE
MARTIN ROTARY
CONVERTER

10 K.W. 220 VOLTS A.C. 110 VOLTS D.C.

M.F. BACON
A.H. RENSCH

At the same time the efficiency shows a rapid rise to about 75 per cent for a 40 per cent load and from that point goes up gradually, attaining a maximum of 83 per cent at 125 per cent load, and holds up exceedingly well to 100 per cent overload. The direct voltage follows very closely the alternating current input, showing very little internal drop in either the machine or the transformer.

The same test applied to the unit when operated on the next transformer tap indicates no notable changes as shown in the curves of Figure 2. The direct voltage averaged about 3 volts lower than that resulting from the use of the maximum tap. The efficiency and power factor tam to approximately the same values as in the previous case with slighily slower rise at lower loads, thus giving a more sweeping character to the respective curves.

Each of these tests were taken with

the apparatus connected as shown in the wiring sketch A.

Among the features of perhaps lesser importance yet worthy of consideration to the designer are the division of current and load in each of the phases. The data shows the division of load and current quite clearly.

The drop in the field current in excess of the corresponding drop in the terminal voltage can be explained by the fact that the test started when the machine was cold and as the machine warmed up the field resistance increased slightly.

Figures 4,5, and 6 show the results of tests similar to the ones shown in Figures 1, 2 and 3, except that in the former cases a battery load was used instead of the lamp load.

The respective curves show practically the same characteristics for the battery load as for the lamp load and the same remarks will

DIAL ARM
AUX. COIL
COLLECTOR RING
INSULATED RING WITH ONE POINT CONTACT
V
G

apply in the respective cases. The only noticeable difference is that the curves of the power factor and efficiency in the case of the battery loads are slightly more sweeping than in the case of the lamp loads.

The flux distribution under the relative parts of the field were determined by measuring the e.m.f. generated in a search coil wound on the armature, the span of the coil being nearly equal to one pole span. The scheme of connections is as shown in the diagram. One terminal of the coil is permanently connected to ground (shaft or core), the other is connected to a slip ring. On the end of the shaft is fastened an insulated disc with one knife blade contact edge connected to ground. Once each revolution this contact edge, which is approximately even with the circumference of the disc, makes a contact with a brush. The brush is mounted on

an arm which may be set at any position around the circumference of the disc. The position of the supporting arm may be definitely located by means of an indicator and dial graduated in degrees. By connecting a voltmeter or galvanometer across the brush on the contact disc and the brush on the slip ring, it may readily be seen that a voltage impulse will be experienced once during each revolution. Instead of measuring these impulses directly, however, it is far more satisfactory to balance them by a steady external e.m.f. and then measure the balancing e.m.f. The balance was obtained by adjusting the potential rheostat until the condition of no current was obtained as indicated by a zero deflection of the galvanometer. As the supporting arm for the contact brush is then moved by small increments around the dial, the e.m.f. due to the flux under the same

position in the field and the generated e.m.f. is therefore a measure of the relative flux. The curves obtained in this test are discussed in another part of this thesis.

In all of the tests mentioned thus far all results were taken on the unit as a whole. For more definite information it is desirable to know the relative proportion of the losses in the machine and the transformer separately.

In the determination of transformer losses and efficiency we consider the fact that:

Per cent efficiency = Output/Input

$$= P_L \times 100/(P_L + P_c + P_{SL} + P_i)$$

in which:

P_L = the total input

P_c = the copper loss of primary and secondary.

P_{SL} = the stray load losses.

P_i = the core loss.

The core loss depends upon the flux density, which of course will vary slightly with varying conditions but the total is large compared with the variations so that it is quite practical to call the iron loss a constant quantity. We may therefore measure it under open circuit as indicated in sketch B, applying the full voltage to the primary.

The copper and stray load losses are determined together by short-circuiting the the secondary as shown in sketch C and impressing sufficient voltage on the primary to cause current to flow in the transformer equal to the varying load current of the machine in service. Values taken are represented by the curve shown in Figure 7. Thus for the efficiency at any particular load it is merely a case of adding the constant iron loss to the loss at that load as indicated on the

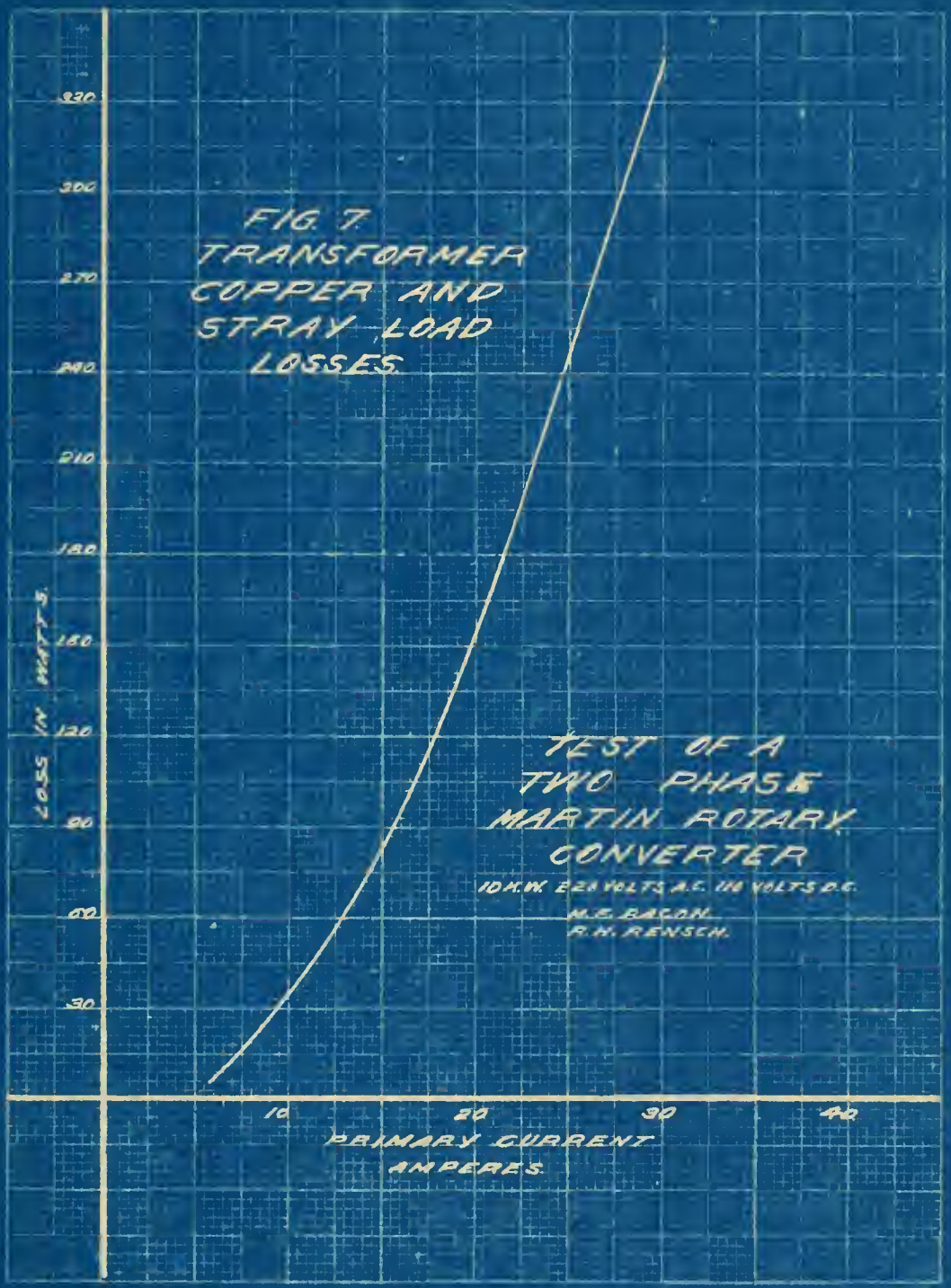


FIG. 7
TRANSFORMER
COPPER AND
STRAY LOAD
LOSSES.
TEST OF A
TWO PHASE
MARTIN ROTARY
CONVERTER
10 K.W. 224 VOLTS A.C. 110 VOLTS D.C.
M.E. BACON
R.H. RENSCH.
LOSS IN WATTS.
320
300
270
240
210
180
150
120
90
60
30
10
20
30
40
PRIMARY CURRENT
AMPERES.

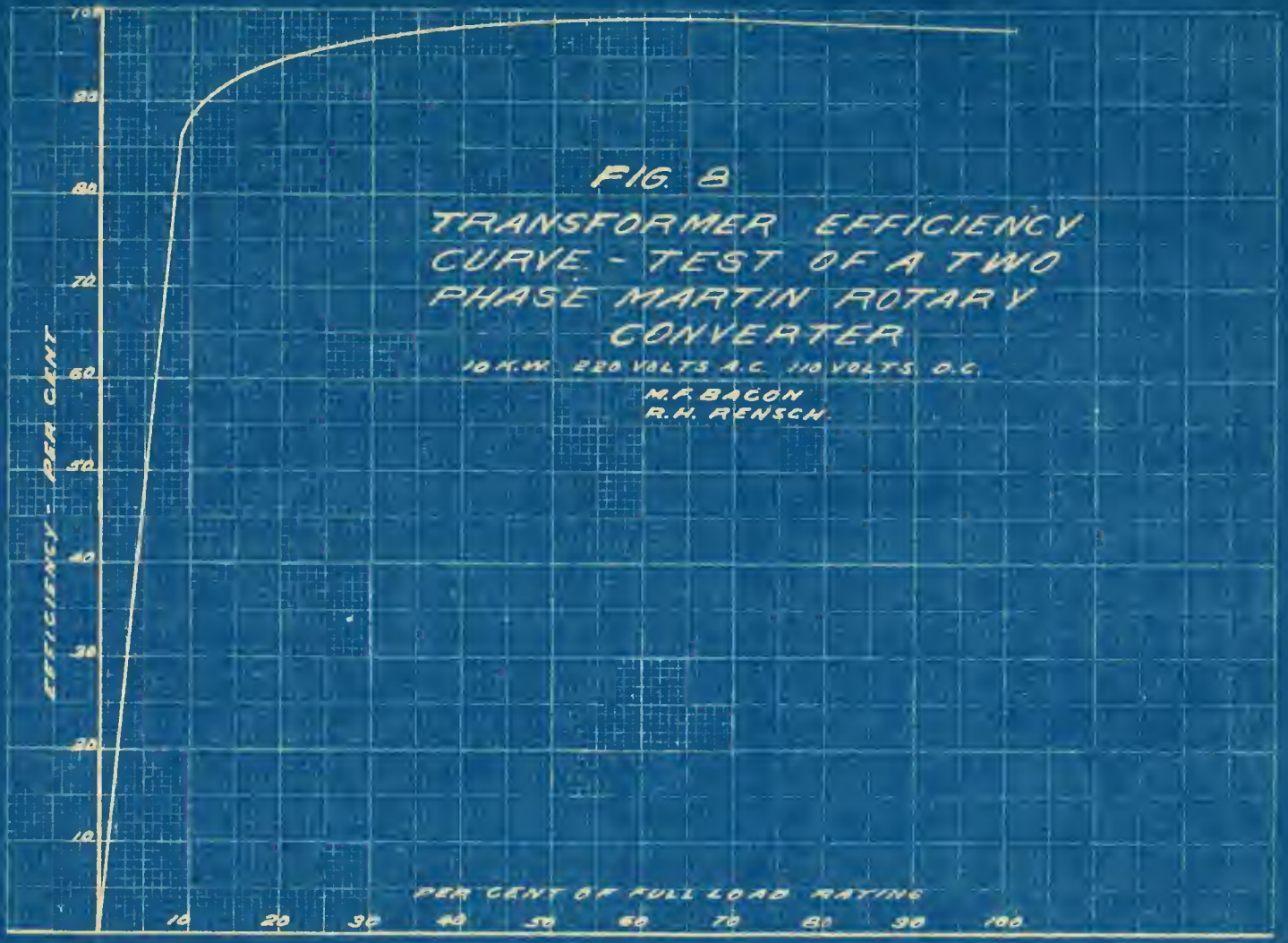
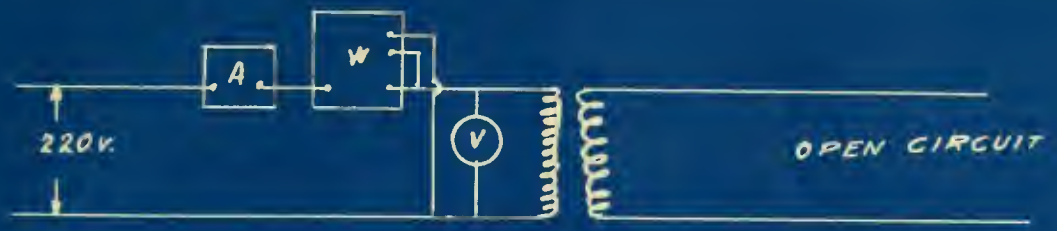
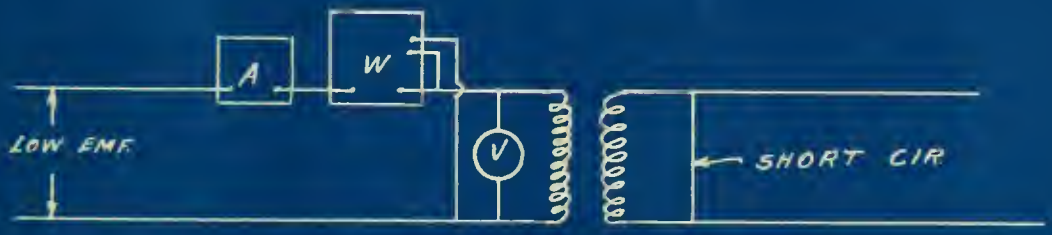


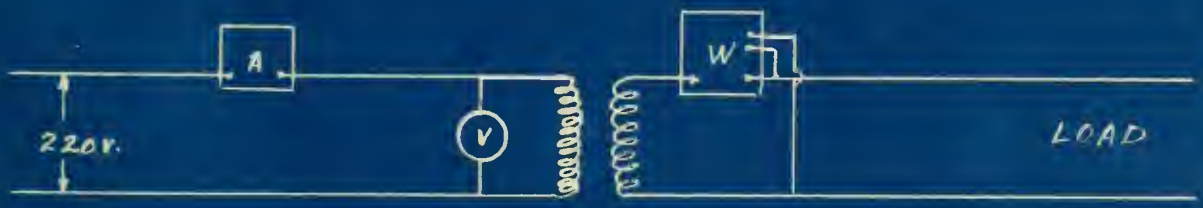
FIG. 8
TRANSFORMER EFFICIENCY CURVE - TEST OF A TWO PHASE MARTIN ROTARY CONVERTER
10 K.W. 220 VOLTS A.C. 110 VOLTS D.C.
M.R. BACON
R.H. RENSCH
EFFICIENCY - PER CENT
90
80
70
60
50
40
30
20
10
PER CENT OF FULL LOAD RATING
10
20
30
40
50
60
70
80
90
100



CORE LOSS MEASUREMENT.



COPPER AND STRAY LOAD LOSS.



LOAD

curve of Figure 7, and the efficiency may be calculated according to the above formula.

Thus for example at the 30 ampere load:

Phase A power input = 12900 watts.

Phase B power input = 12600

Total power input = 25500 watts.

P_c and P_{SL} = 340 watts. (Figure 7)

P_i (constant) 163 watts.

Eff. = 25500 x 100/(25500 + 340 + 163)

= 98%

The transformer efficiency curve plotted for a number of such points is shown in Figure 8. Similar tests made with the secondary on the three highest taps gave data so nearly identical as shown in the data recorded that the same curve is used for all.

No good means were available for getting a separation of losses in the machine alone, so this part of the experiment was

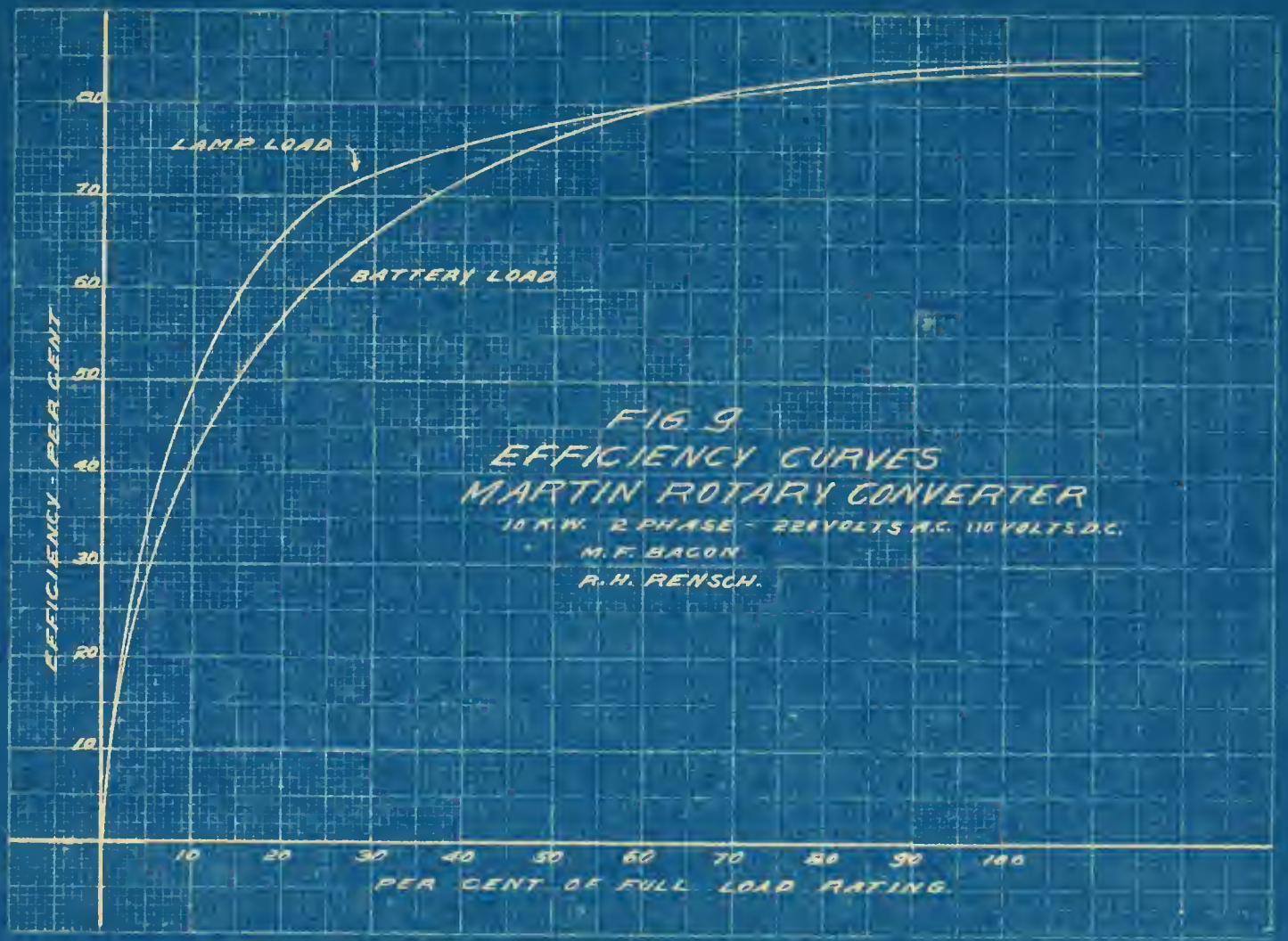


FIG. 9

EFFICIENCY CURVES

MARTIN ROTARY CONVERTER

10 K.W. 2 PHASE - 220 VOLTS A.C. 110 VOLTS D.C.

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dispensed with and the overall efficiency of the machine calculated from the overall efficiency of the machine and transformer and the efficiency of the transformer alone. The curve shown in Figure 9 indicates that the machine has a higher efficiency for low lamp loads and a higher efficiency for high battery loads. There is no apparent reason as to why there should be a difference in the efficiency of the machine when carrying the two loads; and it is reasonable to believe that if a more accurate determination could be made on the machine alone that such a marked difference would not exist.

However, the curves of Figure 9 indicate in general the efficiency of the machine, and show that the efficiency attains a value of approximately 85 per cent when the machine is carrying a full-load.

A few words will now be said in regard

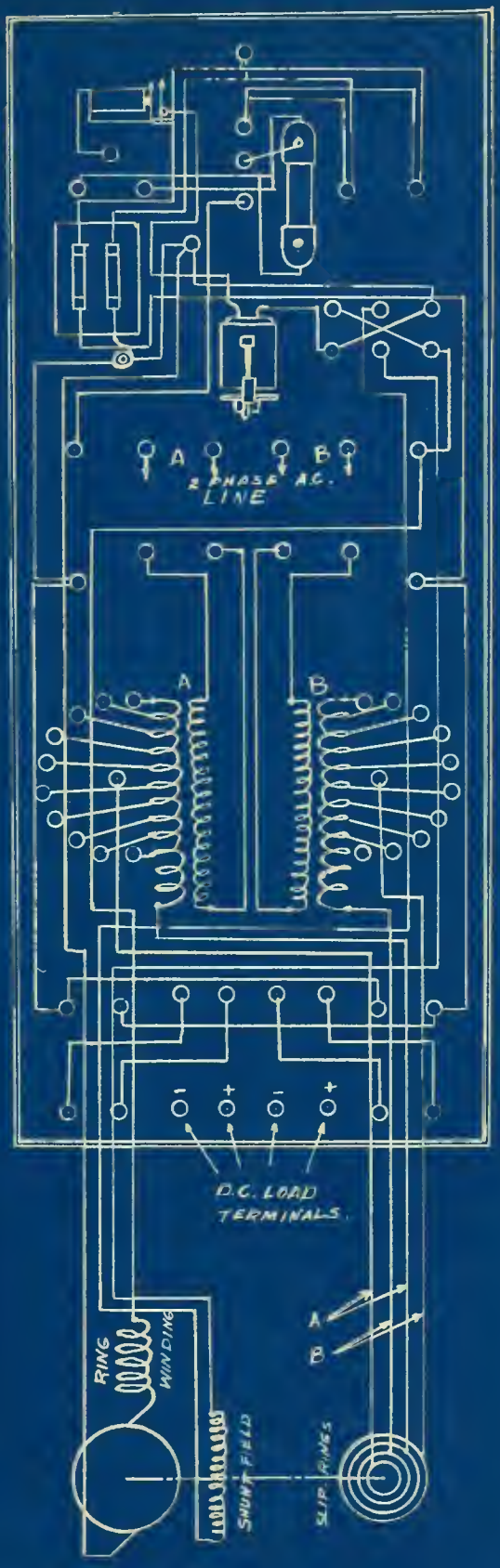


DIAGRAM
REAR VIEW
SWITCH BOARD
PANEL.

MARTIN ROTARY CONVERTER

TWO PHASE.

to the switchboard equipment on the machine.

Reverse currents from a battery are prevented by a reverse current circuit breaker. Overloads are taken care of by a release solenoid and contact making ammeter. In a similar manner a predetermined minimum current value may also open both the alternating and direct current circuits, thus requiring less attention when the battery charge becomes almost complete.

In starting up the rotary the four pole single throw switch is thrown in and the machine starts on the alternating current side. The shunt field circuit is equipped with a reversing switch. In case the machine should come up in the wrong polarity the switch is closed in the reverse direction and a current is produced in the field coils which tends to reverse the polarity. If the magnetomotive force of the shunt field

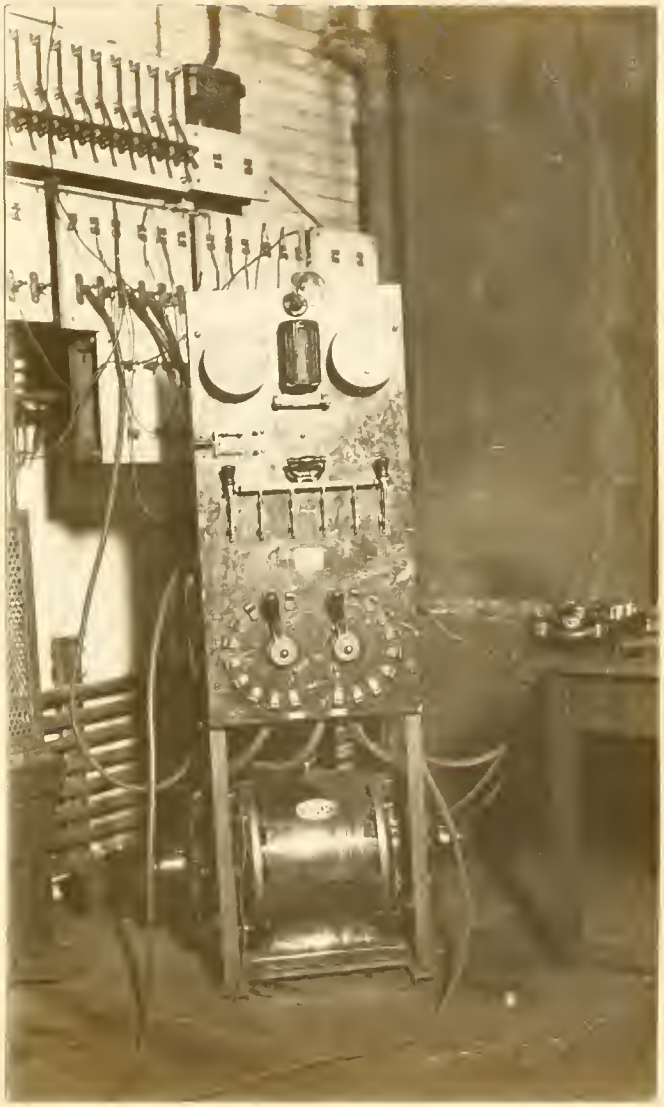
circuit is greater than that of the armature, the polarity of the field poles will be reversed. The armature will then slip back half a pole and take up the new position with more or less stability, depending upon the rotative inertia of the armature. In this position no current will exist in the field windings for then both sets of brushes are of the same potential. In this position adjacent pole tips are of the same polarity and the armature will naturally slip back another half pole. The field switch again reversed will then lock the armature in step in the proper polarity.

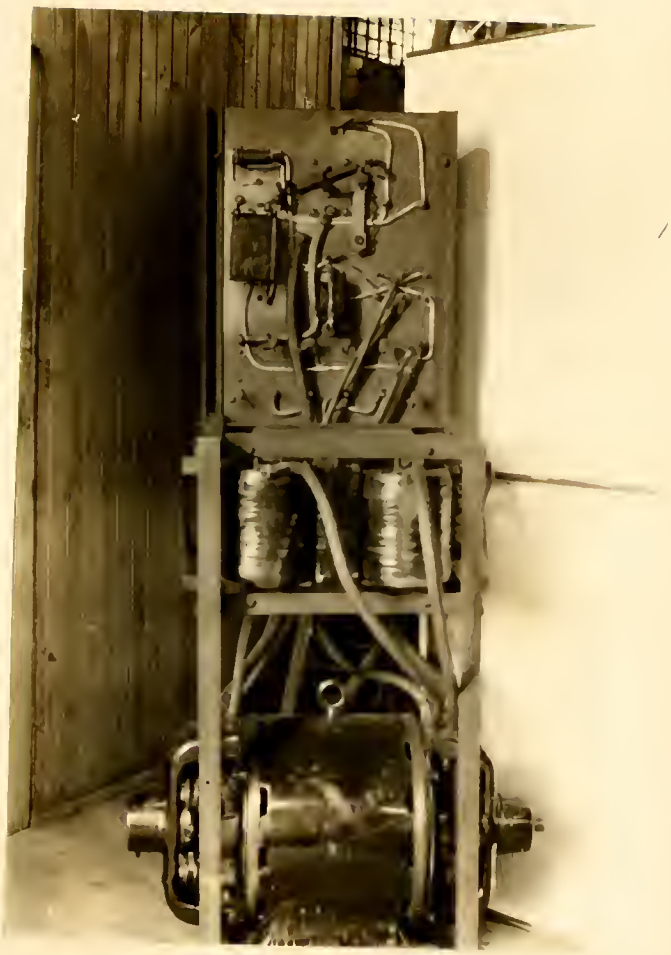
The observed and calculated data will be given on the following pages.

It has been the aim of the authors of this thesis to obtain as accurate results as possible and to have them true to commercial practice, and it is hoped that the results

obtained will be of value to the designer and manufacturer of the machine.

The authors are indebted to Mr. Martin of the Northwestern Electric Company, who very kindly gave them the use of the machine free of charge.





Data for test number one, incandescent lamp load.

Current		Power		Total Power
A	B	A	B	
6.20	6.20	0.71	00.67	1.38
7.50	8.40	1.31	1.40	2.71
9.90	10.60	2.00	2.05	4.05
12.10	12.35	2.50	2.60	5.10
15.00	15.60	3.20	3.30	6.50
17.80	18.40	3.85	3.90	7.75
21.40	21.90	4.70	4.70	9.40
24.60	25.00	5.35	5.35	10.70
28.00	28.00	6.75	6.10	12.85
29.40	29.60	6.80	6.75	13.55
33.30	33.40	7.70	7.60	15.30
36.70	36.80	8.20	8.10	16.30
42.00	42.00	9.20	9.00	18.20
44.80	44.60	9.80	9.60	19.40
48.40	48.00	10.60	10.20	20.80
52.00	51.60	11.40	11.00	22.40

Data of test number one continued.

Direct voltage.	Load current	Alter-nations	Field current	Apparent power.
125.0	0	125	1.35	2.73
124.0	11.0	125	1.34	3.48
124.0	20.5	124	1.32	4.50
123.5	30.0	124	1.30	5.35
124.0	40.0	124	1.30	6.73
124.0	49.0	123	1.30	7.96
124.0	60.0	123	1.30	9.54
123.5	70.0	122	1.30	10.90
124.0	80.0	122	1.30	12.31
123.0	90.0	122	1.30	13.00
123.5	101.0	122	1.30	14.70
122.5	110.0	122	1.30	16.20
122.0	122.0	121	1.29	18.50
121.50	131.0	121	1.28	19.70
121.0	141.0	121	1.27	21.20
121.0	152	120	1.25	22.80

Data of test number one concluded.

Power factor.	D.C. power.	Effic-iency.
50.5	0	0
78.0	1.36	50.4
90.0	22.54	62.7
95.4	3.71	72.7
96.5	4.96	76.2
97.4	6.08	78.4
98.5	7.45	79.2
98.2	8.65	80.9
100.0	9.92	77.2
100.0	11.10	82.0
100.0	12.49	81.6
100.0	13.48	82.6
998.5	14.90	81.9
98.5	15.91	82.1
98.2	17.08	82.1
98.2	18.40	82.3

Data of test number two.

Current		Power		Total
A	B	A	B	Power
5.5	7.0	0.58	0.75	1.33
6.8	8.5	1.60	1.35	2.95
8.8	10.4	1.73	1.95	3.68
11.2	12.8	2.35	2.60	4.95
14.1	15.5	3.04	3.26	6.30
15.7	18.2	3.61	3.87	7.48
20.3	21.7	4.42	4.71	9.13
23.1	24.7	5.05	5.35	10.40
26.2	27.8	5.22	6.01	11.23
29.6	31.2	6.50	6.84	13.34
32.4	34.2	7.18	7.50	14.68
35.8	37.4	7.80	8.28	16.08
38.4	40.0	8.40	8.80	17.20
42.4	44.2	9.30	9.70	19.00
44.8	46.6	9.80	10.20	20.00
47.2	51.0	10.80	11.20	22.00
51.6	53.6	11.30	11.72	23.02
54.6	56.6	11.90	12.32	24.22
58.4	60.0	12.66	13.08	25.74

Data of test number two continued.

Apparent power	Power factor	Field Current	Load Current
2,76 3.34	48.2	1.40	0
3.34	88.3	1.36	10.0
4.23	87.1	1.35	20.0
5.28	93.7	1.35	29.5
6.51	96.9	1.35	40.0
7.88	95.1	1.33	49.0
9.25	98.6	1.33	61.0
10.52	98.9	1.33	70.0
11.88	95.5	1.32	80.0
13.39	99.8	1.32	91.0
14.65	100.0	1.32	100.0
16.10	99.9	1.31	111.0
17.26	99.6	1.30	120.0
19.05	99.9	1.30	132.0
20.10	99.6	1.28	140.0
21.60	100.0	1.28	152.0
23.16	99.6	1.26	160.0
24.45	99.2	1.25	170.0
26.05	98.9	1.24	182.0

Data of test number two concluded.

Direct Voltage	Load power.	Efficiency
119	0.0	0.0
118	1.18	40.0
118	2.36	64.2
118	3.48	70.2
118	4.73	75.0
118	5.79	77.4
118	7.20	78.9
119	8.34	80.2
118	9.44	83.9
119	10.82	81.2
119	11.90	81.1
118	13.10	81.5
118	14.18	82.4
118	15.58	82.0
118	16.51	82.7
117	17.80	81.0
116	18.56	80.5
115	19.54	80.6
115	29.02	81.4

Data for test number three.

Current		Power		Total
A	B	A	B	Power
5.0	6.5	0.55	0.71	1.26
6.4	8.0	1.05	1.23	2.28
8.4	9.9	1.65	1.85	3.50
10.6	12.1	2.22	2.45	4.67
13.2	14.6	2.88	3.10	5.98
16.2	17.5	3.52	3.70	7.22
19.2	20.6	4.20	4.48	8.68
22.0	23.5	4.84	5.12	9.96
25.2	26.6	5.51	5.82	11.33
28.2	29.6	6.20	6.50	12.70
31.2	32.8	6.80	7.20	14.00
34.6	36.2	7.60	8.00	15.60
37.2	38.8	8.10	8.50	16.60
40.4	42.0	8.88	9.20	18.08
44.2	46.0	9.70	10.10	19.80
47.0	48.8	10.24	10.62	20.86
50.0	51.8	10.82	11.24	22.06
53.2	55.0	11.56	12.00	23.56

Data for test number three continued.

Apparent power	Power factor	Field Current	Load Current
2.53	49.8	1.22	0
3.17	72.0	1.22	9
4.00	87.4	1.22	20
4.99	93.6	1.22	29
6.11	97.8	1.22	39
7.40	97.6	1.22	49
8.75	99.1	1.22	60
9.99	99.8	1.22	70
11.40	99.5	1.22	80
12.71	99.9	1.22	90
14.10	99.4	1.21	100
15.60	100.0	1.21	112
16.72	99.4	1.20	120
18.10	99.9	1.20	130
19.85	99.7	1.19	142
21.10	98.8	1.18	151
22.40	98.3	1.17	160
23.80	98.9	1.17	170

Data of test number three concluded.

Direct Voltage	Load Power	Efficiency.
114	0.00	900
115	1.03	44.4
115	2.30	65.7
115	3.34	71.5
115	4.48	74.9
115	5.64	78.1
115	6.90	79.5
115	8.05	80.7
115	9.20	81.2
115	10.35	81.5
114	11.40	81.5
114	12.78	81.9
114	13.69	82.4
113.5	14.74	81.7
112.5	16.00	80.8
112.5	17.00	81.5
111	17.75	80.6
111	18.85	80.3

Data of test number four, with a battery load and maximum voltage tap.

Current		Power		Total
A	B	A	B	Power
6.2	6.2	0.67	0.71	1.38
8.1	8.8	1.20	1.35	2.55
11.2	12.0	2.35	2.30	4.55
13.4	13.9	2.80	2.85	5.65
16.6	17.1	3.55	3.60	7.10
18.7	19.2	4.05	4.10	8.15
22.0	22.3	4.80	4.80	9.60
25.5	25.7	5.60	5.55	11.15
28.2	28.2	6.20	6.13	12.33
31.6	29.8	7.00	6.95	13.95
34.5	34.5	7.60	7.50	15.10

Data of test number four continued.

Load Current	Direct Voltage	Load Power	Apparent Power.
0	125	0.0	2.73
8	125	1.00	3.72
24	125	3.00	5.10
32	125	4.00	6.00
43	126	5.42	7.41
50	125	6.31	8.34
62	125	7.75	9.70
74	125	9.25	11.25
82	124	10.18	12.40
94	124	11.65	13.50
102	123	12.55	15.20

Data of test number four continued.

Power Factor	Field Current	Efficiency.
50.5	1.35	0.0
68.6	1.36	39.2
89.3	1.34	65.9
94.2	1.33	70.8
95.7	1.35	76.3
97.8	1.33	77.4
98.9	1.32	80.8
99.1	1.31	82.9
99.6	1.30	82.4
100.0	1.30	83.5
99.4	1.29	83.2

Data for test number four, second secondary tap.

Current		Power		Total
A	B	A	B	Power
5.5	7.0	0.58	0.75	1.33
8.0	8.8	1.30	1.45	2.75
12.3	12.9	2.60	2.65	5.25
18.4	18.8	4.00	4.05	8.05
24.2	24.5	5.30	5.20	10.50
31.3	31.6	6.95	6.90	13.85
	Third secondary tap.			
5,0	6.5	0.55	0.71	1.26
6.7	7.6	1.20	1.30	2.50
11.7	12.4	2.50	2.60	5.10
15.8	16.4	3.45	3.50	6.95
20.3	21.0	4.55	4.55	9.10
28.0	28.2	6.20	6.15	12.35

Load Current	Direct Voltage	Load Power	Apparent Power
0	121.5	0.0	2.76
11	121.5	1.34	3.70
32	121.0	3.87	5.54
54	121.0	6.54	8.18
70	120.0	8.43	10.70
96	119.5	11.48	13.82
	Third secondary tap		
0	117.0	0.0	2.53
10	117.0	1.17	3.14
31	117.5	3.64	5.30
48	115.5	5.55	7.08
64	116.0	7.43	9.10
90	115.0	10.35	12.35

Data for test number four concluded.

Power Factor	Field Current	Efficiency.
74.4	1.40	0.0
94,8	1.27	48.7
98.5	1.26	73.7
98.3	1.26	80.0
100.0	1.24	80.3
	Third secondary tap.	
49.8	1.22	0.0
79.6	1.20	46.8
96.1	1.20	71.4
98.4	1.20	79.9
100.0	1.21	81.6
100.0	1.20	83.9

Transformer Test.

Copper and stray load losses.

Current		Power		Total
A	B	A	B	Power.
6,6	6.2	6	5	
11.2	10.45	20	18	
17.2	15.90	54	46	
25.0	24.2	129	110	
31.0	28.8	182	158	
39.6	36.8	285	240	
	Tap number two.			
9,8	9.1	18	15	
17.0	15.8	56	49	
19.8	18.4	76	65	
27.3	25.2	147	125	
31.0	28.8	186	162	
	Tap number three.			
9,8	9.1	17	15	
16.9	15.7	55	49	
29.6	27.6	172	152	

Transformer Test.

Load Losses.

Power A	Power B	Total Power	Line Current	Efficiency
550	700	1250	3.0	88.5
4450	4500	8950	10.4	97.7
6700	6720	13420	15.8	98.4
9000	8900	17900	21.1	98.2
11200	11000	22200	26.3	98.1
12900	12600	25500	30.0	98.0
	Second Tap.			
500	700	1200	3.0	88.0
4320	4350	8670	10.30	97.7
6180	6160	12340	14.50	98.3
8200	8200	16400	19.40	98.1
11400	11000	22400	27.00	98.1
	Third Tap.			
490	660	1150	3.0	87.6
4450	4500	8950	10.40	97.8
10700	10700	21180	25.5	98.8

Transformer Test.

Iron Loss.

Current in phase A = 0.6 ampere

Current in phase B = 0.6 ampere

Power in phase A = 60 watts.

Power in phase B = 103 watts.

Total iron loss = 163 watts.

Resistance of primary 7.25 volts-72 amperes.

Resistance of secondary 2.50 volts-26 amperes

Resistance of secondary 0.76 volts-45.5 amperes.

Flux Distribution Test.

Angle	Deflection. No-load.	Angle	Deflection
0	5.0	250	9.0
350	4.1	245	0.9
340	1.9	240	1.8
330	1.2 Rev.	235	3.2
320	3.0	230	3.7
315	4.0	225	4.0
310	8.0	220	8.1
305	11.1	215	11.9
300	13.6	210	13.0
295	16.1	205	16.1
290	15.2	200	16.2
285	12.1	195	14.0
280	10.8	190	11.5
275	8.1	185	8.9
270	4.1	180	4.0
265	4.1	175	4.0
260	2.0	170	3.5
255	0.9	165	3.0

Flux Distribution Test.

100 Amperesload.

Angle	Deflection	Angle	Deflection
10	15.0	310	5.1
5	12.1	308	7.5
0	7.1	305	8.0
355	6.6	300	9.5
345	2.8	295	11.0
340	2.0	292	11.5
338	0	290	11.8
335	2.8	288	12.1
330	4.2	286	12.9
327.5	5.8	284	12.3
325	6.1	282	11.1
322.5	6.7	280	11.1
320	6.9	275	10.9
318	6.1	270	5.4
316	5.0	265	5.0
314	4.7	260	4.9
312	4.0	255	2.0

Flux Distribution Test.

100 ampere load.

Angle	Deflection.	Angle	Deflection
250	1.0	187,5	10.1
248	0.0	185	9.1
245	2.3	182.5	6.9
240	3.7	180	6.2
235	6.1	175	5.0
233	5.9	170	4.0
230	5.9	165	1.0
227.5	5.0	160	0.0
225	3.2	155	1.1
222.5	3.0	150	4.0
220	3.9	145	4.1
217.5	5.0	140	5.2
215	7.0	135	3.5
210	8.9	137.5	4.1
205	10.5	132.5	3.8
205	11.0	130	5.0
195	11.1	127.5	7.1
190	10.0		

Machine Efficiency.

Per cent Load.	Efficiency on Battery Load.	Efficiency on Lamp Load.
15	51.9	59.4
30	67.0	72.1
45	74.1	76.7
60	78.6	78.9
75	81.5	81.0
90	83.6	83.0
100	84.4	83.9